32 GHz Carrier Generation and 200 Mbit/s Error Free Data Transmission in a Radio Over Fibre System

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***Abstract*— A simple method for the generation and modulation of Millimetre Waves as the base of a Radio over Fibre downlink system is presented. The technique relies on the amplification of a component of a frequency comb by stimulated Brillouin scattering. The method provides a high up conversion grade and a simple implementation of a modulation setup. An error free downlink transmission of a 200 Mbit/s signal is shown for the back to back case and radio propagation at a 32 GHz carrier is verified.**

***Keywords* – Millimetre Wave, Stimulated Brillouin Scattering.**

I INTRODUCTION

Radio over Fibre (RoF) systems as possible intended photonic communication systems are based on the transmission of an optically generated and modulated carrier in the Millimetre Wave (mm-Wave) range. RoF systems have the advantage that the complexity is located in the base station where the carrier frequency is generated and the modulation process takes place. The head station is an optic/electronic converter, which works also as a transmission unit. It transmits the signal to the mobile receiver via air. Several solutions for mm- Wave signal generation systems using optical components have been presented so far. The most common method relies on the heterodyne superposition of two phase correlated frequency components in a photo detector (PD). The frequency separation corresponds to the mm-Wave at the output of the PD. The easiest way for the generation of two phase correlated frequencies is the external modulation of a continuous wave (CW) by a Mach-Zehnder modulator (MZM) [1].

The MZM is driven in the non-linear regime by an electrical CW-source in the range of several GHz. The MZM works in the double sideband suppressed carrier (DSSC) mode. The lower and the upper first order sideband represent the two correlated frequency components. Due to this, the modulation frequency has to be only the half of the photonic carrier frequency [1]. Other techniques utilising mode locking [2], phase locking [3], [4] or optical frequency shifting by single side band modulation [5-7] have been verified so far. Furthermore, the injection locking [8] technique and its stabilisation through fast electronic feedback [9] have been investigated. The required microwave synthesizer at the desired mm-Wave frequency or the high complexity of the set up limits all these methods for the generation of two phase correlated frequency components. These components require special designed equipment and are very sensitive to environmental influences.

The optical injection locking requires an extremely stable environment for an error free application for instance. A temperature shift of a fraction of a degree is sufficient to cause the system to fall out of lock if standard DFB lasers are being used [10].

In this paper, a simple method based on stimulated Brillouin scattering is presented. Contrary to the presented method in [11], here the optical carrier is modulated [12]. A quite similar idea but using phase instead of an amplitude modulation for the photonic up conversion has been briefly proposed in [13]. The solution for generating the carrier signal, presented in this paper, uses only of the shelf components of optical telecommunications. Hence, it is a low cost set up. Furthermore, it is not fixed to one wavelength but can be adjusted to any required carrier frequency.

II STIMULATED BRILLOUIN SCATTERING

Stimulated Brillouin Scattering (SBS) is the first nonlinearity encountered in silica optical fibres, as the transmitted power increased. For CW-laser diodes, the lowest threshold for this effect in several km of Standard Single Mode Fibres (SSMF) is in the order of a few milliwatts [14, 15]. Due to an interaction of the incident light wave with the material (silica), an acoustic wave is generated. This can also be seen as a periodic change in the refractive index. At this grating the pump wave is scattered and a Stokes wave is generated having the opposite propagation direction as the pump wave. The Stokes wave is frequency down–shifted in the range of 11 GHz [16].

For the natural Brillouin gain a bandwidth of 28 MHz was measured. The broadening of this bandwidth can be made by a phase modulation and a combination of several pump lasers [17] or by an external binary phase shift keying with an arbitrary pulse pattern of the pump wave [18].

SBS has a spontaneous emission noise (SEN) that can be 500 times larger than in Raman amplifiers [19] and a noise figure that can be 20 dB higher than that for an ideal amplifier [20]. However, in [21] it was reported that driving the amplifier in the saturation regime, using short amplifier lengths, a low signal detuning and relatively high input signal powers could significantly reduce the SEN. These characteristics are all considered in our system. Hence, the additional noise due to SBS is expected to be minimised considerably. The additional phase noise is comparable to that induced by a commercially available Erbium Doped Amplifier [22].

III EXPERIMENT

Preliminary results were discussed previously [15, 16, 23, 24]. Here we will give a detailed overview of the system idea.

The half of the light emitted from a narrowband fibre laser (wavelength: 1550.12 nm; linewidth: < 1 kHz; output power: P_{out}= 16.5 mW) was modulated by a Mach-Zehnder amplitude modulator (see Fig. 1 MZM1). The modulation signal was a 6.4 GHz sinusoidal wave and has a power of 35 dBm. The MZM was driven in the nonlinear regime to generate harmonics around the carrier with a frequency separation that corresponds to the modulation frequency. Either the lower quadratic operation point (OP) for generating the odd order sidebands (carrier is suppressed), or the upper quadratic OP for the generation of the even order sidebands (including the carrier) can be chosen. For this approach the generation of odd order sidebands was applied due to the fact that the carrier is suppressed. Figure 2 shows the frequency comb at the modulator output. The magnitudes of the

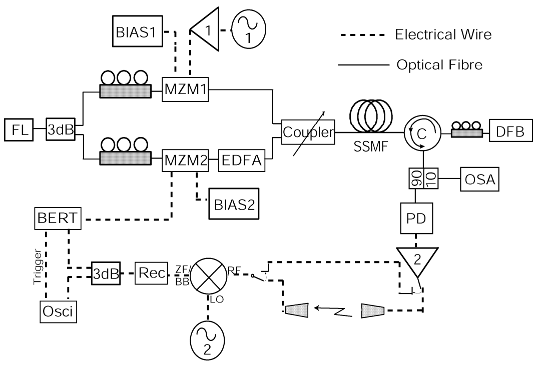

Figure 1: Experimental set up of the Radio Over Fibre system. FL: Fibre Laser; MZM: Mach-Zehnder Modulator; EDFA: Erbium Doped Fibre Amplifier; BERT: Bit Error Rate Tester; DFB: Distributed Feedback Laser Diode; PD: Photo Detector; OSA: Optical Spectrum Analyzer; REC: Receiver Unit; SSMF: Standard Single Mode Fibre; C: Optical Circulator.

harmonics follow a Bessel function [25]. According to Fig. 2, the creation of sidebands up to the order of 7 can be realised by raising the power of the modulation signal. The other 50% of the light of the fibre laser was modulated by a second MZM (MZM2) and amplified by an Erbium Doped Fibre Amplifier to a power level of 10.4 dBm. In order to simulate a realistic data stream a Pseudo Random Bit Sequence with a pattern length of $1 \cdot 10^{-23}$-1 bit and a data rate of 200 Mbit/s was used as a modulation

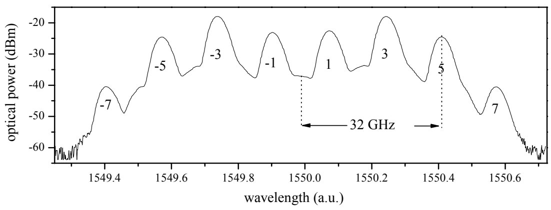

Figure 2: Frequency comb: Odd order sidebands and a suppressed carrier.

signal. The separated carrier and the frequency comb were launched into a 50.45 km long SSMF via a tunable coupler. A Distributed Feedback laser diode (DFB LD) with a line width of 3 MHz and a power of 4.1 mW emitted the pump wave for selective sideband amplification. It was sent via an optical circulator from the opposite direction into the same SSMF (see Fig. 1). The wavelength of the pump was tuned in such a manner that the Brillouin gain wavelength corresponds to that of the sideband of the frequency comb that should be amplified. This was done by temperature tuning of the pump laser. Due to the fact that the amplification system was driven under the Brillouin threshold the amplified sideband has the same properties as the original signal (excepting the power). The SBS amplification process enhanced the 5^{th} order sideband from a power level of -35.68 dBm to a level of -3.37 dBm. The amplified carrier and the SBS amplified 5^{th} sideband were coupled out via the circulator (see

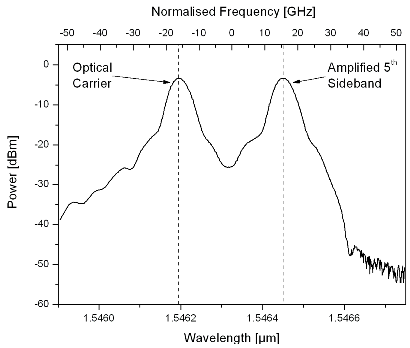

Figure 3: Optical spectrum at the circulator output.

Fig.1). The emitted spectrum is shown in Fig. 3. All undesired frequency components were reduced in power due to the natural attenuation of the SSMF. The tunable coupler was used in order to adjust the powers of the optical components to be equal. Due to the fact that the base frequency (drive signal of MZM1 = 6.4 GHz) was up converted by the factor 5, the mm-Wave signal had a frequency of 32 GHz. This frequency corresponds to the frequency separation of the two optical components in Fig. 3. The signals were superimposed in a PD with a 3 dB responsivity bandwidth of 27 GHz (Newport D-15ir). In the PD the signal was squared. Thus, frequencies in the region $2\omega_{opt}$, ω_{opt} and ω_{opt1}-ω_{opt2} were generated. Due to the inertia of the PD, only the mix frequencies ω_{opt1}-ω_{opt2} was detected, which corresponds to the desired mm-Wave frequency. For this approach, ω_{opt1} represents the modulated optical carrier which was heterodyned with the 5^{th} order sideband.

IV RESULTS

The superposition results in a modulated signal at a 32 GHz carrier. Due to the inefficient optic/electric conversion, the power of the data signal was low. An electrical amplifier (amplifier (2) in Fig. 1; gain: 30 dB; bandwidth: 2-50 GHz) enhanced the signal to a power level of -40 dBm, as can be seen in Fig. 4

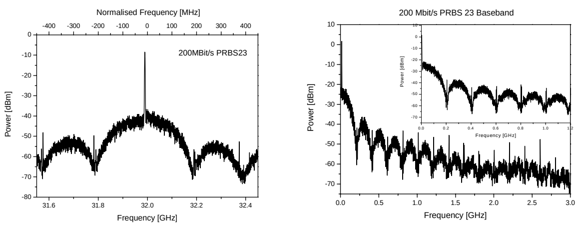

Figure 4: Left: 200 Mbit/s modulated 32 GHz RF Signal; Right: 200 Mbit/s down converted into base band.

(left). The spectrum was recorded at the output of the RF amplifier (2). An analysis of the carrier signal itself resulted in a power level of -40 dBm and a line width of less than 300 Hz[1].

[1] The measurement was limited by the resolution of the electrical spectrum analyser (RBW= 300Hz).

The down conversion of the modulated carrier into base band has been executed by an external mixer. In order to convert the 32 GHz signal into base band the LO frequency was chosen to be 16 GHz. The signal was enhanced again by a receiver unit. The receiver unit operated as a base band amplifier with a zero gain bandwidth of 3.21 GHz and a maximum gain of 40 dB. The usage of the receiver unit was necessary to circumvent the conversion loss of the external mixer.

Due to the low power of the data signal, the detection at the oscilloscope and the BERT was very crucial. It has been observed during the measurements that there was a threshold at which the receiver unit started amplifying. In case the optical power was high enough to drive the system, the eye became clear and the bit error rate decreased to an error free transmission. In case the optical power decreased slightly, also the power of the RF signal decreased logarithmically. Therefore, the eye got closed and the BER increased dramatically to values of up to $1 \cdot 10^{-4}$. Measurements that describe the BER versus the optical power at the PD failed due to the described non-linear property of the receiver unit. During the error free transmission, an eye diagram has been recorded which can be seen in Fig. 5. A

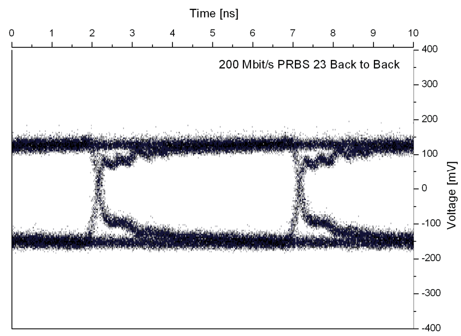

Figure 5: Optical spectrum at the circulator output after propagating in a 50.45 km SSMF (back to back).

voltage of 270 mV_{pk-pk} was measured. This result was attained after optimising all possible parameters to achieve the highest power level at the PD to be 0 dBm. As can be seen, the eye is opened without any significant distortions in the centre. The ripples at the edges are originated by the bit muster generator that generates overshoots. The edges are sharp, which is caused by the amplification bandwidth of the receiver unit. In order to underline the BERT measurement a Q-factor analysis has been done. The Q-factor is a synonym for the Gaussian error integral and offers a method to investigate the probability density function of the two signal states ("0" and "1") at a certain time. According to Fig. 5, a Q-factor of 8.405 was calculated for the back to back case. This value corresponds to a BER of $21.6 \cdot 10^{-18}$.

In order to realise a radio down link, the signal was transmitted between two pyramidal horn antennas. As can be seen in Fig. 6, the power of the eye has increased slightly to a value of 280 mV_{pk-pk},

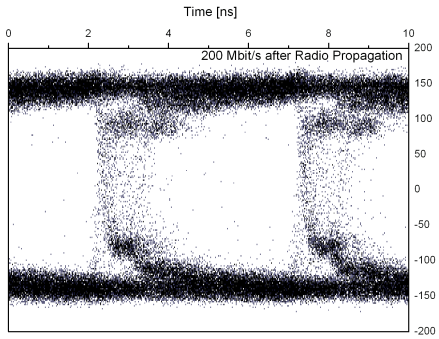

Figure 6: 200 Mbit/s data signal after radio propagation.

which is caused by the higher gain of the receiver unit. Therefore, also the signal to noise decreased, which leads to a closure of the eye. BER measurements for the case of radio propagation resulted in values of up to $1 \cdot 10^{-2}$.

The crucial error free data transmission can simply be improved by the application of optical pre-amplifiers at the PD or RF amplifiers in the electrical path. Thus, an error free data transmission can also be expected if the signal is transmitted via air.

V DISCUSSION

A very simple method for the generation and modulation of mm-Waves was shown. It is a significant alternative for the application in Radio over Fibre systems. Only standard components of optical telecommunications are used for the set up. Neither an RF generator higher than 6.4 GHz nor any other expensive equipment was required for the generation of a 32 GHz carrier signal. If the variety of possible frequency comb generation techniques such as a phase modulation or four wave mixing is considered, the frequency limitation depends only on the bandwidth of the PD. The modulation bandwidth is limited neither by the Brillouin gain bandwidth nor to any other obvious restriction.

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